Differences in electrodermal activity between a night of recovering sleep compared to a night of poor sleep induced by partying – an explorative study

Bachelor Thesis

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Abstract

The present study aimed at acquiring more knowledge about electrodermal activity in relation to sleep research. Polysomnography has been the gold standard in sleep research. However, lots of limitations go along with this method as for example being (almost always) bound to a laboratory. EDA is a measurement known since over one hundred years already, but has not been used frequently in sleep research yet. Since this measurement can bring many advantages into sleep research, more should be known about it in this conjunction.

The differences in EDA have been compared between a night of recovering sleep and a night of disturbed sleep which was induced by partying. It was expected that the average SCL as well as number of SCR's and total amplitude of SCR's would be higher in a night of good sleep compared to a night of poor sleep. This was measured by means of the Q-Sensor which needed to be worn around the wrist by participants during the particular nights. Moreover, participants had to perform a vigilance task the following morning, were asked to fill in subjective questionnaires (KSS and PSQI) and to keep a sleep diary. This included subjective ratings of sleep quality for the four nights of the experiment.

The results of the study confirmed the hypothesis concerning SCL, but not for the number of SCR and total amplitude of SCR's. In addition, the results of the study reveal tendencies concerning the number of sleep storms that have been found in earlier studies. Further expectations that have been formulated had reference to hit-rate, miss-rate, false-alarm rate and sensitivity as well as reaction times on the vigilance task, at which only the hypothesis expecting a higher hit-rate after a night of good sleep was confirmed. The other hypothesis that had reference to the vigilance task could not be confirmed; the number of SCR's, total amplitude of SCR's and SCL were not found to be significantly higher during the vigilance task after a night of poor sleep compared to a good night.

For future research, the number of SCR's as well as the total amplitude of SCR's are two concepts that should be studied more deeply, since great individual differences have been found. Moreover, it would be of advantage to find a manipulation assuring that people actually experience a night of poor sleep (accordance with subjective ratings and conditions assigned), to be sure that it really comes to a night of poor respectively good sleep. Then it would be possible to find out more about, amongst others, the tendencies concerning sleep storms which have been displayed in the current study.

Samenvatting

Het doel van het actuele onderzoek was het om meer kennis te verwerven over huidgeleiding in samenhang met slaaponderzoek. Tegenwoordig is polysomnografie de “gold standard” in slaapstudies. Echter zijn er veel nadelen met deze meetmethode verbonden waaronder de gebondenheid aan een laboratorium. Huidgeleiding is een meetmethode die al over honderd jaar bekent is, maar nog niet vaak in slaaponderzoek gebruikt wordt. Deze methode blijkt echter veel voordelen te hebben tegenover polysomnografie en daarom is het interessant om hier meer over uit te vinden. De verschillen in EDA werden dus vergeleken tussen een nacht van goede slaap kwaliteit en een onrustige/slechte nacht die geïnduceerd werd door feesten. Het werd verwacht dat de gemiddelde SCL, de hoeveelheid SCR’s en de totale amplitude van SCR’s hoger zouden uitvallen na een nacht van goede kwaliteit vergeleken met een slechte nacht. De metingen werden doorgevoerd met behulp van de Q-Sensor (Q 1.0) die van de participanten om de pols gedragen moest worden tijdens de bepaalde nachten. Daarboven was de vraag aan de proefpersonen om twee subjectieve vragenlijsten in te vullen (KSS en PSQI) en een slaap dagboek te houden, waarin onder andere subjectieve beoordelingen van de nachten, gedurende de twee weken van onderzoek.

De resultaten van de studie hebben de hypothese met betrekking tot het gemiddelde SCL bevestigd, dit was echter niet het geval voor de hoeveelheid SCR’s en de totale amplitude van de SCR’s. Bovendien laten de resultaten neigingen zien wat betreft de hoeveelheid aan ‘sleep storms’ die in eerder onderzoek werden gevonden. Verdere verwachtingen die geformuleerd werden hadden betrekking op de hit-rate, miss-rate, false-alarm rate en sensitiviteit net als reactie tijden tijdens de vigilantie taak. De hypothese met betrekking tot de hit-rate was de enige verwachting die bekrachtigd werd door het huidige onderzoek. De hypothesen die nog meer betrekking hadden tot de vigilantie taak konden niet geconfirmeerd worden; hoeveelheid van SCR’s, totale amplitude hiervan en gemiddeld SCL waren niet significant hoger na een slechte nacht vergeleken met een goede nacht.

Hoeveelheid SCR’s en totale amplitude van de SCR’s zijn twee concepten die in toekomstig onderzoek verder onderzocht moeten worden aangezien er grote individuele verschillen gevonden werden. Bovendien zou het van voordeel zijn om een betere manipulatie te vinden om te solideren, dat mensen daadwerkelijk slecht oftewel goed slapen (zodat de condities overeenkomen met de subjectieve beoordeling). Dat maakt het mogelijk om meer uit te vinden over de neigingen met betrekking tot sleep storms die in deze studie gevonden zijn.

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Introduction

In our modern society a shift towards an academic population can be observed. More high school students start studying at universities every year and fewer students consider to do an apprenticeship (Centraal Bureau voor de Statistiek, 2011). With university different aspects of the student's life are about to change. Students need to face many challenges during that period of life like adapting to a new environment, being confronted with different expectations regarding achievement and of course changes in lifestyle. One aspect that belongs to most students college life is going out, clubbing, house parties and so on. This results in very irregular sleep patterns, usually involving sleep deprivation or sleep loss.

The present study focuses on college students as they belong to the group of people sleeping least of all. People between age 20 and 30 sleep less than do people in other age groups (Takahashi, 2003; Wolfson & Carskardon, 2003). Moreover Takahashi illustrates that this particular age group suffers more from daytime sleepiness than older people do. This finding indicates the problems following day time sleepiness and the crucial role of sleep.

Until now the most common measurement for sleep is polysomnography (PSG), however this method is very complicated in usage. PSG is also of high costs, and not the most comfortable way of investigation for participants. Moreover, it is not useful for longitudinal as well as naturalistic research (De Souza et al., 2003). Considering the disadvantages of this measurement device it is time to introduce a new one making research easier, more comfortable for participants and less expensive. This is the reason why the present study aims at shedding more light on the usage of electrodermal activity. In the following sections the backgrounds of the study will be explained, beginning with clarifying sleep and the consequences of sleep deprivation followed by potential measurements of sleep (quality) including PSG, EDA and subjective measurements. Furthermore, it will be illustrated why this study is a small-n explorative, field study and what the utilized design looks like.

Sleep

Sleep is fundamental to the human body to be able to maintain normal functioning. This applies to normal growth, recovering from the day in terms of restorative processes, emotion regulation (Wong et al., 2012), learning and memory functions (Krueger & Obal, 2003; Benington, 2000) as well as a variety of cognitive functions at which the prefrontal cortex plays a major role (Horne, 1993; Harrison & Horne, 1997; 1998; Wimmer et al., 1992 as cited in Drummond et al., 1999). An adequate amount of sleep, mostly 8 to 9 hours per night (Roehrs et al, 1996 as cited by Lund et al., 2010), is necessary to maintain physical and psychological well-being (Wong et al. 2012).

Sleep loss can affect a variety of physiological functions. It has been emphasized that problems with sleeping respectively sleep deprivation are good predictors of many illnesses. As sleep deprivation becomes chronic there is an increased risk of accidents and work absence (Lund et al., 2010). Moreover, Horne (1978) revealed that sleep deprivation is accompanied by decreases of physiological activity like electrodermal activity, cardiovascular activity and body temperature. Mullington et al (2009) highlights the fact that short sleep duration is often followed by increased blood pressure respectively hypertension and cardiovascular morbidity, which are all health risk factors.

Also there are a number of psychological aspects that can be affected by sleep deprivation including diminishments relating to quality of life, impaired social functioning and less vitality (Léger et al., 2006; Léger et al. 2001; Katz & McHoney, 2002; Roth, Jagger & Jin et al., 2006 as cited in Lund et al., 2010). In addition it has been found that sleep quality as well as quantity influences people’s mood. With an adequate amount of sleep the human brain is able to function normally and regulate our emotions (Vandekerckhove et al., 2010 as cited in Wong et al., 2012). For this reason it is not surprising that depressive feelings and sleep loss are found to be closely related (Fredriksen et al., 2004 as cited in Wong et al., 2012).

More studies suggest that there is a relationship between academic performance and sleep. Kelly, Kelly and Clanton (2001) (as cited in Wong et al., 2012) found that students who benefit from 8 hours of sleep per night or more accomplish a better grade-point-average (GPA) in school than do students with less than 7 hours of sleep. This suggests that sleep deprivation has also negative effects on students’ academic achievements. The American College Health Association (2003 as cited in Forquer et al., 2008) argues that sleep deprivation is one of the strongest barriers to academic performance. However, not only the amount of sleep is crucial for proper functioning, the consideration of sleep quality is necessary as well.

Sleep quality

Sleep quality, as the term suggests, describes how well recovered one is feeling after sleep, and thus how satisfying sleep is rated. Besides sleep quality there is also sleep quantity which is part of sleep quality; however there is a difference between these two, whereby the first underlies more subjective measurements like depth of sleep and rated level of recovering while the latter includes sleep duration, number of awakenings and sleep latency (Pilcher et al., 1997). These latter components are easier to measure than precedent ones. In a study by Pilcher et al. (1997) it has been found that sleep quality does not have a strong correlation with sleep quantity, but time actually asleep and sleep quality showed a correlation. Therefore it is necessary to investigate the actual amount of sleep of a person as well as the experienced quality of sleep.

In addition, the results show that physical health problems, as well as psychological complaints like depression and tension are mainly linked to sleep quality, not sleep quantity. Other research indicates that sleep quality can be a fundamental symptom of different sleep and medical disorders (Buysse et al., 1988). Thus, sleep deprivation brings along a lot of negative consequences for sleep quality and thus body functions, which can be diminished.

Sleep (quality): measurements

There has been a lot of research on the topic of sleep, focusing for example on sleep stages, investigating sleep patterns of different groups of people, and studying the consequences of sleep loss. Certainly, there are different possibilities of investigating sleep and sleep quality. On the one hand, there are objective recordings of sleep disturbance data, by which different sleep stadia can be distinguished. On the other hand, although less accurately, information about an individual's sleep can be acquired by subjective measurements which will be explained below. We will focus on objective measurements first. Until now, the gold standard in most sleep studies is the usage of polysomnography (PSG) (De Souza et al., 2003). PSG is a multi-parametric measurement monitoring different aspects of body functioning under which cardiorespiratory and neurophysiological parameters. PSG normally includes Electroencephalography (EEG), Electrooculography (EOG) and Electromyography (EMG) with which it is possible to classify different sleep stadia like rapid eye movement sleep (REM), slow wave sleep (SWS), most often referred to as deep sleep, and so on (Schlüter et al., 1999). In a study by De Souza et al (2003) PSG was compared to actigraphy, which mainly focuses on the movement of a person. The popularity of this device comes from the facts that it is easy to handle, costs are low and there is no necessity for patients to visit a special sleep laboratory or another clinical center for the measurements to be taken (which also applying for the Q-Sensor used in the present study). The actigraph simply needs to be worn around the wrist. PSG in contrast and most other objective measurements are really expensive (Basner et al., 2008). Moreover, PSG is very difficult to use. To be able to take an EEG measurement (one part of the PSG) patients need to wear a sort of cap which is then connected to many electrodes which thereupon stimulate the brain. This technique to measure activity in the cortex is very complex, time consuming, requires the presence of a professional and is advised to be carried out in a (sleep) laboratory (Basner et al., 2008) As the listed disadvantages of PSG suggest, this measurement is not useful in longitudinal and naturalistic studies (De Souza et al., 2003). For this reason, the present study aims at investigating sleep by means of electrodermal activity, which is a different kind of objective physiological measurement having a lot of benefits compared to PSG.

Electrodermal activity (EDA)

Longer than one century it is known that there are relations between what now is known as EDA and psychological factors. The term "EDA [however] was first introduced by Johnson and Lubin (1966 as cited in Boucsein, 2012) as a common term for all electrical phenomena in skin […] including all active and passive electrical properties which can be traced back to the skin and its appendages." (Boucsein, 2012) and has become very popular during the last years. This construct can be further defined as "electrical changes measured at the surface of the skin that arise when the skin receives innervating signals from the brain […] [A]s the pores begin to fill below the surface [the electrical conductance [of the skin] increases in a measurably significant way]" (Affectiva, Inc., 2013).

EDA works as a current which changes according to alterations in the autonomous nervous system. These changes can be interpreted as alterations in conductance (skin conductance – SC) and resistance (skin resistance – SR) (Michael et al., 2004). Miró et al (2002) found out, that during slow wave sleep (SWS) skin conductance level increase up to a maximum, whereas SCL decreases during REM sleep. This finding supports the susceptibility of EDA to sleep deprivation, which is why this measurement will be used during the vigilance test as well, which will be described in one of the following sections. For the present study, this suggests that the SCL of people having a night of poor sleep will be lower, indicating less SWS, than for people experiencing a night of satisfying sleep, which leads to the first *hypothesis (1): SCL is higher in a night of qualitative good sleep compared to a night of poor sleep.* Furthermore, it is possible to make predictions about arousal, attention and emotion with EDA, this measurement is thus applicable in varying fields of research.

In general it has been found that EDA has many advantages compared to PSG. Electrodermal recordings are non-invasive, it is an affordable measurement and usage is simple (Boucsein, 2012). The Q-Sensor, which will be used in the present study, combines actigraphy and electrodermal activity as well as skin temperature can be measured.

The most important aspect of this measurement is the electrodermal ‘response’ (EDR). There is a difference between tonic and phasic electrodermal phenomena, at which tonic refers to Electrodermal level (EDL) and phasic phenomena to EDR. In the book “Electrodermal activity” by Boucsein (2012) he states that there is a clear relationship between the stimulus and the electrodermal response, as is suggested by the term “response”. However, there is also a high chance of the so called “spontaneous” EDA meaning that some responses cannot be linked to certain stimulation. In addition, the height of a single response can be measured, called skin conduction response amplitude (- SCR amp.). It is also possible to see the frequency of EDR’s, so how many responses there are in a given amount of time (SCR freq.). These are two concepts that are compared in the present study as it has been found, that there is a higher chance that EDA is increased when the frequency of “storm” patterns during deep sleep is high (Sano & Picard, 2011). Upon this information, the second *hypothesis (2)* has been formulated*: The amplitude, measured in micro Siemens, of the EDA of participants during a night of good rest is higher compared to the EDA of the same participants during a night of poor sleep.* The term “storm” means that a region of the EDA is characterized by signal sequence of high frequency peaks (Sano & Picard, 2011). Burch in Sano and Picard (2011) has “quantified a storm as a minimum of five galvanic skin responses (GSRs)/min for at least ten consecutive minutes of sleep. In this paper, we defined “storm epochs” as a 30 second epoch with a minimum of three GSRs/30s.” In the current study both criteria for storms as well as storm epochs will be valid.

Sano and Picards’ study reveals a relationship between subjective sleep quality and a higher amount of slow wave sleep (SWS) storm epochs during the first quarter of the night which leads to the third hypothesis of this study: *In a night of poor sleep, participants will have a smaller amount of slow wave sleep which will be indicated by less sleep storms in the EDA compared to the number of sleep storms in a night of good sleep.*

Triangulation

Subjective measures

Furthermore, the present study makes use of triangulation implying that three different types of measurement are used, all eventually testing for sleep quality although in quite distinct manners. Instead of only acting upon the assumption that partying is a manipulation strong enough to induce poor sleep, subjective measurements offer another reference point about sleep quality and quantity. With the Mackworth Clock test (MCT) (Mackworth, 1964) a further indication for the accuracy of the conditions is provided. This makes it possible to assure high validity of the conditions. It is thus possible to check whether EDA data actually describes a night of poor respectively good sleep so that differences can be compared.

Next to the objective measurement EDA, it is possible to make statements about sleep quality by means of subjective methods. These methods provide a more elementary way of investigating sleep quality and daytime sleepiness; they are less expensive and offer a facile alternative to objective measures. One of these measurements is the Pittsburgh Sleep Quality Index (PSQI) which is a self-rated questionnaire to investigate sleep quality and sleep disturbance (Buysse et al., 1988). It includes nineteen individual items covering seven different aspects of sleep quality. The PSQI is said to be a reliable, valid and standardized measurement for sleep quality. In addition, there was a need for an index differentiating between good and poor sleepers. It had to be easy to fill in for patients and facile to interpret for researcher. Being clinically useful with respect to detecting different sleep disturbance is another goal the PSQI was made for. In a study by Buysse et al. (1988) it has been found that patients using this index were actually approving of the ease of usage, as well as the internal consistency and the validity of the PSQI were shown to be high. These are the reasons why the PSQI is used in the present research.

Subjective measurements going beyond sleep quality and rather focusing on daytime sleepiness are another source to underline that sleep was restricted, had poor quality or both. The Karolinska Sleepiness Scale (KSS) is a possible index for sleepiness. Kaida et al (2006) investigated the validity and reliability of the KSS and EEG and found out that the KSS was actually closely related to EEG indicating a high validity in measuring sleepiness. Therefore, this Scale has been chosen for this research.

Sleep, Vigilance and Signal Detection Theory

The third part of the triangulation will be a vigilance test. It is well known that sleep loss or sleep deprivation has negative effects on the mental performance of a person. As cited in Åkerstedt (2006), Balkin et al found that different mental performance tests have different susceptibilities with regard to sleep deprivation or changing sleep patterns. It was pointed out that tests like psychomotor vigilance tests, measuring attention in a continuous monotone way were most sensible.

However, there are different definitions of what is meant by the term vigilance. In this research, the term vigilance will be used to describe the "ability to sustain attention to a task for a period of time" (Davies and Parasuraman, 1982; Parasuraman, 1998). Moreover vigilance decrement is referred to as "the decline in attention-requiring performance over an extended period of time" (Mackworth, 1964). In a study by Oken, Salinsky and Elsas (2006) vigilance is used in terms of sustained attention which is also "the most common scientific usage." This definition equates the one used in the present study.

As mentioned in the definition, vigilance is closely related to some aspects of attention. The term attention usually refers to an activation pattern in the brain which enhances information processing (Oken et al., 2006), which is expected to be impaired after a night of sleep deprivation. This suggests what is expected in *hypothesis (4): The reaction times on the psychomotor vigilance task are higher after a night of poor sleep compared to a night of good sleep.* In accordance with this hypothesis it is also expected that (*hypothesis 5): The number of hits is significantly higher after a night of good sleep compared to a night of poor sleep.* These two hypotheses employ the Signal detection theory (SDT), stating that either a signal to be detected is present or that this is not the case (for more details see Appendix 1). This signal detection is influenced by a bias called sensitivity, which can be thought of as a bottom-up process expressing how good a person is able to discriminate the signal from the noise (Wickens et al., 2004, p.84).

The formula to calculate sensitivity is as follows: d' = z [p (hits) – z [p (false alarms)] (Macmillan & Creelman, 2005). In accordance with the two hypotheses mentioned earlier it is thus expected that the sensitivity is higher after a night of good sleep compared to a night of poor sleep.

An aspect of attention fitting best with vigilance, also very important for SDT, is sustained attention, because vigilance means being alert over a sustained period of time. However, alertness and attention are not equal. Alertness refers to attention, but it also includes cognitive processing (Oken et al., 2006). Rockstroh et al. (1987) found, that the attentional system seems to be more engaged when it needs to cope with new information compared to dealing with old stimuli, thereby improving sustained attention. As the contrary is the case during a psychomotor vigilance task (coping with the same stimuli only) it is suggested that participants need more effort to fulfill the task assuming that they are more aroused taking the test after a disruptive night compared to a night of good rest. However, since Horne et al (1978) suggested that sleep deprivation brings along a decrease in physiological functions under which electrodermal activity, in *hypothesis (6)* it is expected that: *The EDA of participants after a night of good rest has an higher amplitude measured in Siemens (suggesting more arousal) during the psychomotor vigilance test compared to the EDA of the same participants after a night of poor sleep.*

Purpose

Many studies about sleep deprivation and its negative effects on a variety of cognitive functions, health and learning tried to investigate as many participants as possible to be able to make a statement or prediction possible to generalize (Studies investigating sleep patterns of college students e.g. 313 participants in a study by Forquer et al. 2008; 1125 participants in a study by Lund et al. 2010). However, not much can be found with respect to sleep and electrodermal activity (Miró, Cano-Lozano and Buela-Casal, 2002).

Indeed there is a lack of studies looking more closely at the individual (Molenaar, 2004). It is important to create a precise picture of what effects can be found and how they differ between individuals. Only if there is substantial information about which concepts are sensitive enough to make investigations reasonable, it is possible to expand research to more general levels to be able to draw promising conclusions. Since time for the present study is limited and as it is of explorative kind, only four participants were chosen for investigation to gain a better insight into the potentials of EDA for sleep research. In addition, there have been a number of limitations in the few earlier studies like insufficient measurements and no statistical analysis (Miró et al., 2002). The present studies thus aims to diminish limitations by being aware of earlier constraints. If this exploratory study succeeds, it will be possible to set up future research finding out new aspects of sleep, probably with conclusions being more realistic than those of laboratory studies today. This study might be the foundation for future interventions about sleep deprivation, the development of new sleep applications and much more.

Methods

Participants

The four participants were aged between 20 and 23 years. Two participants are male, two are female and they are all of German nationality. Three of the four participants were students whereof two of them study at the University of Twente and one studies at the Saxion Hogeschool Enschede. The fourth participant will begin his studies next semester. Three of them are friends of the experimenter and one is the experimenter herself. Moreover, the participants all fulfilled the criteria of being healthy and showing normal sleeping patterns. Participation was voluntary and subjects received no financial contributions.

Measurement devices

This research uses the Q-Sensor (Q 1.0) to take EDA and actigraphy measurements. Measurements are of exosomatic kind which means that an external current is used. There are two possibilities that can be applied, either "*direct current* (DC) or *alternating current* (AC) to the skin" (Boucsein, 2012). In the present study the first one will be utilized, direct current, this is keeping voltage constant and recording EDA directly in skin conductance (SC) units. The Q-Sensor comes with a 3-axis accelerometer which provides the opportunity to also measure movement during the night. The recordings were sampled with a frequency of 32 Hz and the sensor was synchronized to the experimenter's laptop so that the time was the same for all measurement devices. The storage capacity of the micro SD card inside the Sensor makes 28 days of constant measurement with a frequency of 32 Hz, possible. Recharging is possible via a universal serial bus (USB) port. Moreover, the Q-pod will be used to measure EDA during the vigilance task. This device uses sensors which are applied to the subjects palm of the hand rather than to the person‘s wrist. This device is more sensitive and more eligible for short periods of measurement.

To visualize the data, Q-Software will be utilized, which will then be analyzed by means of Matlab and SPSS. Next to the mentioned devices for the triangulation, participants are also asked to keep a sleep diary including evaluation of the quality of the four nights, time they went to bed and so forth.

Procedure

Participants first were asked to fill in a screening questionnaire about their medication intake, consume of coffee and cigarettes as well as the PSQI on the day before the experiment started. The information revealed by these questionnaires was used to decide which participants may take part in the research. (The exclusion criteria are : normal sleep pattern : going to bed between 10pm and 2am, getting up sometime between 6am and 11am; not more than three cups of coffee per day; no heavy smokers – more than three cigarettes a day). Furthermore, they had to perform a short version of the Vigilance task.

At the beginning of the study, participants were asked to sign a contract stating that they agree with the terms of investigation. Considering the fact that the participants needed to use the Q-Sensor by themselves, they received oral instructions as well as a short written guidance. Thereupon, participants received their personal arrangement of the four different observation occasions, telling them which nights they had to take measurements with the Q-Sensor as well as on which days they were supposed to go partying. The Q-Sensor needed to be worn around the wrist (on the given nights) as soon as the person went to bed with the intention to sleep. After the particular nights, participants were asked to come to University at 11am to fill in the KSS and their sleep diary first and to perform the psychomotor vigilance task subsequently. This procedure was repeated after all of the four nights.

Stimuli and Task procedure – vigilance task

The vigilance test was taken in the morning hours as a decline in performance during this time of day is observable in real-world settings (Wickens et al., 2004, p.345). The MCT has been chosen as this test requires participants not only to react quickly, but also to detect signals correctly. It is a visual test, which was selected as this sort of vigilance tests is most sensitive to sleep disruptions (Wickens et al., 2004, p.344). During the MCT the participant had to look at the display (sitting at about 0,5m away from the display) keeping track of a red, moving dot for 30 minutes. The period of 30 minutes has been elected as studies have found out that after this time, a notably decrease in performance can be observed (Davies & Krkovic, 1965). Whenever the dot skipped one position, the participant had to hit the space bar as fast as possible and reaction times were measured. Moreover, false alarms as well as misses have been recorded.

Settings of the MCT have been culled in a way that the task was of low arousing level, but still provided a number of skips (and thus reaction times) high enough for being able to draw significant conclusions. The company providing the Clock test (Inquisit) chose four skips per minute whereas Mackworth chose only 23 skips per hour (Lichstein et al., 2000). In the present study the medium between the two was chosen, thus two skips per minute which left us with 60 skips for the total 30 minutes of the test. This made the test less arousing compared to a test with four skips per minute, thereby making it more sensitive to the effects of sleep deprivation. During the task, EDA was measured on two of the four participants utilizing the Q-pod (a measurement device more sensitive to small changes in EDA than the Q 1.0) to be able to make statements about the level of arousal of the person.

Data analysis

Randomization test, T-test & Chosen Design

The consequences following sleep deprivation e.g. impairments in cognitive functions have been found to be varying among individuals; however they tend to be stable within individuals (Van Dongen et al., 2004 as cited in Michael et al., 2012). For this reason the present study investigated individuals on four different occasions, including two nights supposed to be of poor sleep quality (one condition) and two nights being of refreshing nature (second condition). Partying has been used as manipulation so that participants experienced nights of poor sleep. Studies have found, that alcohol dependent people show a poorer sleep quality than do people not dependent on alcohol (Irwin et al., 2006). This suggests that alcohol has negative effects on sleep and as most people drink alcohol during parties, probabilities of experiencing a disturbed night are enhanced.

For the investigations of the present study, a *Small-n repeated measures design with 2 conditions and replicates* (Dugard, File & Todman, 2012*)* has been used. This ANOVA analog design, "[…] a design that is analogous to designs for use with analysis of variance." (Dugard, File & Todman, 2012, p.13) has been chosen as this research is of exploratory kind, which makes randomization tests a very good method to use. These tests have a higher sensitivity then do normal *t*-tests when comparing small groups. Randomization tests have the advantage that they usually achieve a high internal validity thus eliminating alternative explanations by the possibility to randomly assign treatments to observation occasions.

The *Small-n repeated measures design with 2 conditions and replicates* adopted to the present study implied that for each of the four participants there had to be two observations for each of the two conditions (condition 1 = poor sleep; condition 2 = good sleep) thus 1, 1, 2, 2. These conditions were assigned to each participant in random order which was possible with six different arrangements (4! / 2! 2!). Since there were four participants taking part in this research, there were actually 1296 possible arrangements (6x6x6x6=1296). Assuming that the test has a significance level of 5% the potential number of arrangements is more than sufficient.

The data assembling took place during two weeks. Wednesday and Thursday were possible days for measurement as these are the days for clubbing in Enschede. Thus, conditions were assigned randomly over the four possible days (two Wednesdays and two Thursdays) for each participant. During the four different nights, the hypotheses were tested including the following dependent variables: (1) number of sleep storms per night defined by the criteria mentioned earlier (see section EDA), (2) Average SCL per hour (3) Average number of SCR (frequency) per hour and (4) Average total amplitude of SCR’s per hour.

The test statistic of the ANOVA analog design is the *difference between condition means within a participant.* As the macro is designed in a way that the mean of the first condition is subtracted from the second one, the second condition needs to be higher (if this is not the case or does not coincide with the hypothesis tested, condition 1 and 2 need to be changed e.g. condition 1 = good sleep instead of poor sleep, condition 2 = poor sleep instead of good sleep. This has been carried out in the case of: “misses”, “false alarms” and “reaction times”.) To obtain the reference set which was needed for later calculations, SPSS was used to choose a random sample with replacement of 2000 rearrangements of conditions within participants.

Utilizing macros for data processing

The book by Dugard, File and Todman (2011) comes with the adequate macros one requires to process the data in a way that is in accordance with the different randomization tests. The term “macro” stands for a syntax which if carried out automatically analyses the data allowing for replication of the analysis. Utilizing the macro fitting the selected design, SPSS calculates the reference set, the test statistic and both the one- and two-tailed test-significance. If the significance comes out at a percentage of above five, this means that more than 5% of the samples in the reference set have a difference between the mean of condition two and the mean of condition one which is at least as high as the test statistic in the experience. This indicates that the results of the experiment are not of significant kind.

To be able to use the given macro (for macro see Appendix 2), it is also necessary to utilize a particular datasheet arranging data in SPSS in a way that the macro can “understand” it (see Appendix 3). In the present study this has been carried out for eleven different datasets. Five for the MCT including “reaction times”, “hits”, “misses”, “false alarms” and “sensitivity”; and another six with respect to the EDA data during the night under which “average number of SCRs per hour”, “average SCL per hour” and “average amplitude per hour” which were the same for during the vigilance task.

Results

Skin conductance level, skin conductance response and total amplitude

In the present study it was expected that the average SCL during a night of good sleep was higher compared to a night of poor sleep. The test statistic for average SCL was as high as (*M2* = 1.3694) - (*M1* = .9283) = .4411 (see Table 1.1), with a one-tailed significance of p = .033 (< p = .05, thus significant), indicating that in 3.3% of a random sample of 2000 rearrangements, values of condition one were lower than of condition two. Calculations for the hypotheses concerning average number of SCR's per hour (p = .282) and total amplitude per hour (p = .306) were not significant (see Table 1.2 & Table 1.3 in Appendix 5).

Table 1.1

Minimum, maximum as well as mean and standard deviation of average SCL per condition

	N	Minimum	Maximum	Mean	Standard deviation
Poor sleep	8	.24	2.00	.93	.51
Good sleep	8	.55	2.81	1.37	.76

Sleep storms

Sleep storms were expected to be more prevalent in nights of good sleep. The analysis displayed that the number of sleep storms ranged from zero to four storms per night (an example is given in Figure 2) in the first condition (poor sleep) and from zero to five storms per night in the "good" condition at which five nights included more than two sleep storms (see Table 2.). This suggests that there are no substantial differences between the conditions which was also revealed by the statistical analysis. The one-tailed significance did (p = .361 > p = .05) not reach the significance level.

Table 2.

Approximate number of sleep storms, subjective ratings of sleep quality and KSS results per condition per participant

Approximate nr. of sleep storms	Rating	KSS	Condition	Participant
3	Okay	8	Poor sleep	1
5 (at which 1 very long one)	Good	5	Good sleep	1
4	Okay	8	Good sleep	1
3	Bad	8	Poor sleep	1
1	Very well	7	Poor sleep	2
2-3	Normal	5	Good sleep	2
3-4	Normal	6	Good sleep	2
4	Normal	8	Poor sleep	2
0	Disturbed	2	Good sleep	3
1	Disturbed	3	Good sleep	3
3-4	Very well	8	Poor sleep	3
0-1	Very well	9	Poor sleep	3
2	Okay	8	Poor sleep	4
1	Bad	5	Good sleep	4
3	Bad	8	Good sleep	4
0	okay	9	Poor sleep	4

The KSS asks the participant to rate the state of alertness on a scale from 1 (extremely alert) to 9 (extremely tired) see Appendix 4.

Subjective measurements

The PSQI revealed that three of the four participants stated usually sleeping about seven hours per night at which the overall quality was estimated to be good. Ratings of sleep quality in the sleep diary did in 68.75 % of the cases not match the assigned condition (see Table 2.). (Here) Nights were overall rated as being of good/okay quality more often than as being of poor sleep (11 of 16 nights).

Results of the KSS (example KSS see Appendix 6) were compared to the actual conditions as well, displaying twelve ratings consistent with the assigned condition. Two ratings were not in agreement with the conditions at all, and two further ratings only under the condition of taking all four ratings of one person into account.

Mackworth Clock Test

The statistical analysis with respect to the Vigilance task revealed that the mean of reaction times in condition two (after poor sleep) has not been significantly higher than the reaction times in condition one as $p > .05$ ($p = .31$). The test statistic in contrast shows a difference between condition two ($M = 445.38$; $SD = 33.23$) and condition one ($M = 442.16$; $SD = 33.89$) as high as 3.22.

The mean of hits in condition one (poor sleep) was lower than the mean of condition two (good sleep) with a significance of $p = .048$, at which the test statistic was equal to 4.875 = 52.63 – 47.75. The significance was very close to .05, therefore the analysis has been carried out two additional times for a count of arrangement statistics at least as large as 96 and 92 and with a significance of $p = .048$ and $p = .046$. The null hypothesis was rejected as $p < .05$. The results concerning the miss-rate did not reach significance level ($p = .065$) neither did the calculations regarding false-alarm-rate ($p = .14$).

Furthermore, it was expected that sensitivity was significantly higher after a night of good sleep (indicated by the numbers written in bold see Table 1.4 Appendix 5). Indeed, results did not reach significance ($p = .54$).

Average SCL, number of SCR's and total amplitude during the Vigilance task

In the last hypothesis with respect to EDA it was expected that the total amplitude of SCR's, the number of SCR's and average SCL were all higher during the vigilance test after a night of good sleep compared to the performance after a night of poor sleep. Statistical analyses revealed that none of the conducted calculations were significant. The total amplitude of SCR's reached a one-tailed significance of p = .544, for average number of SCR's the significance was as high as p = .446 and average SCL yielded p = .297.

Individual differences (graphical analysis)

Average SCL per night

Since some of the test statistics suggested that there are great individual differences, graphical analyses have been carried out, of which some are shown below. Figures 1.1 and 1.2 give graphical insight into possible additional individual differences in average SCL during sleep. It is shown that for the two female participants (one and four) the differences between a good night and a poor night respectively SCL are more distinct in comparison to the males.

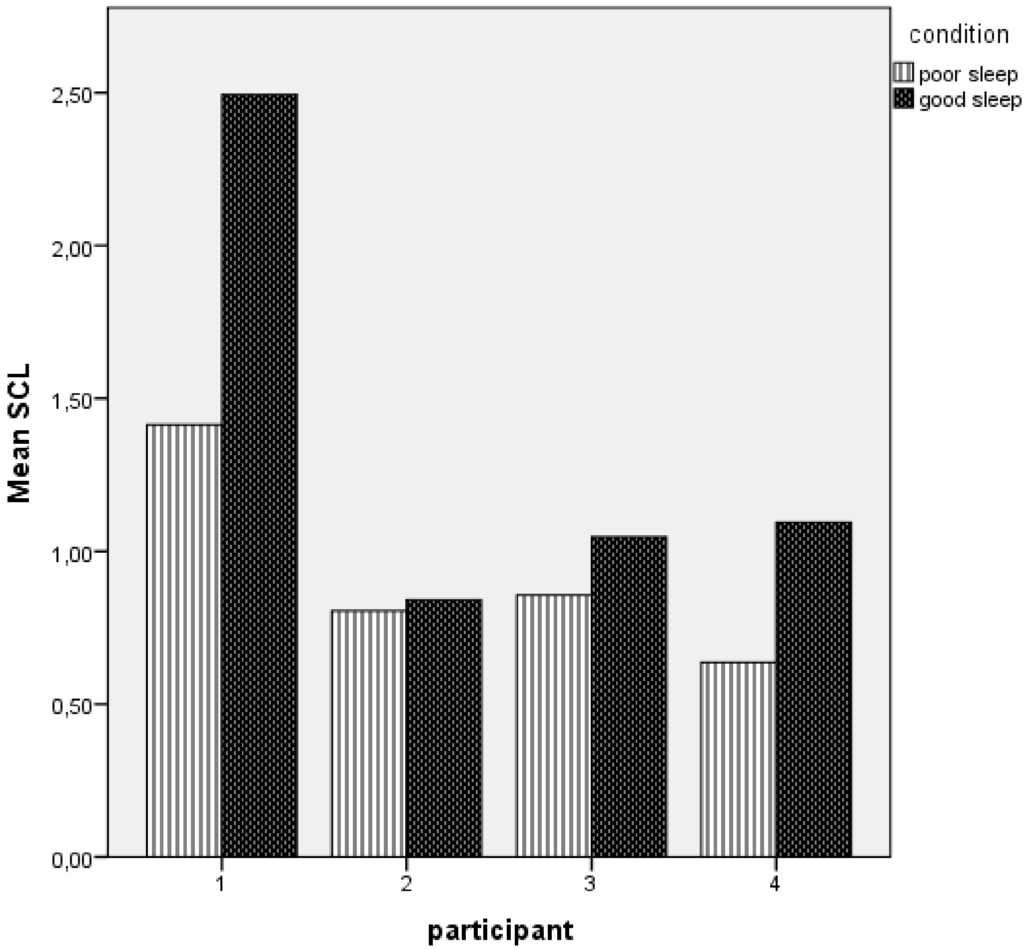

Figure 1.1 Average SCL per hour (in mSiemens) during sleep for each participant per condition

Figure 1.2 shows, that this is only the case for participant one. The nights of the same condition seem to be somehow related. Participant one shows a higher average SCL during nights in the good condition (about 2.2 m Siemens and 2.8 m Siemens) compared to nights of the poor condition (approximately 0.8 m Siemens and 2.0 m Siemens). Indeed, the data displayed in this figure suggests great differences in the nights of the poor condition. The other participants did not show a pattern indicating that both nights of one condition were higher or lower than the nights of the other condition.

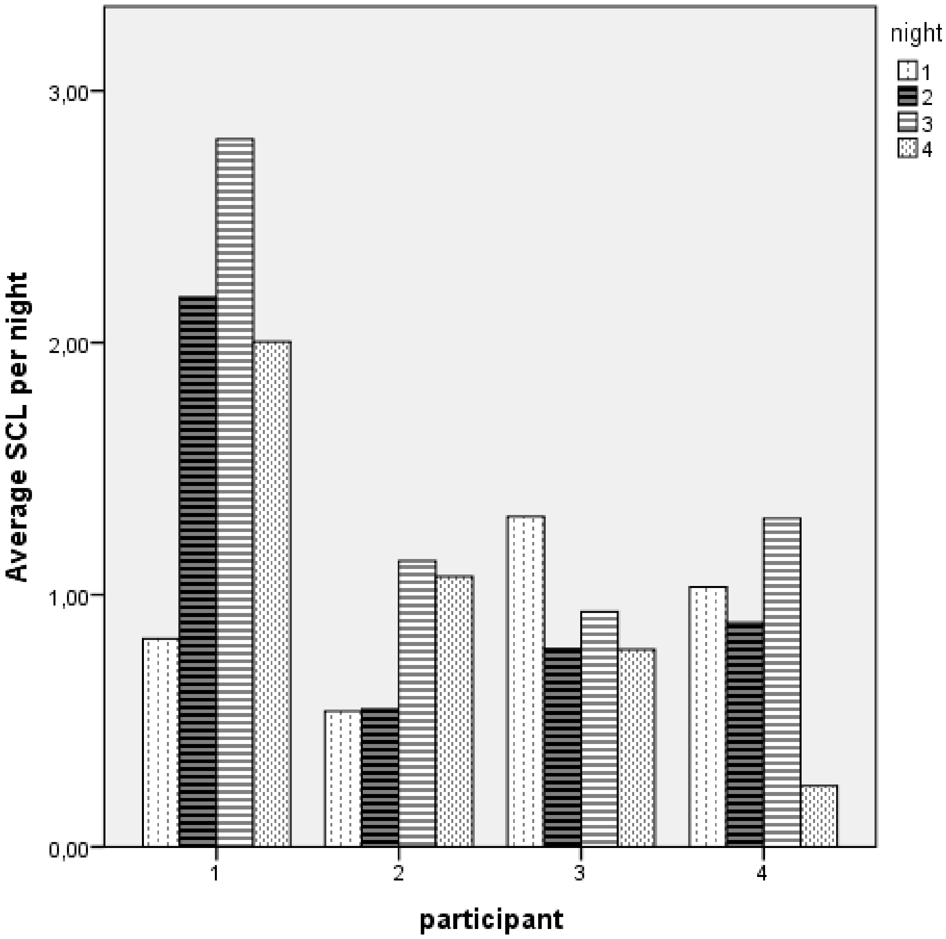

Figure 1.2 Average SCL per hour (in m Siemens) during sleep for each participant for each night apart (Participant 3: night 1 and 2 = good nights; participant1, 2, 4: night 2 and 3 = good nights)

Sleep storms

The graphical analysis of the EDA data respectively sleep storms of participant one showed that nights in the “good” condition showed an earlier onset of sleep storms, as well as a higher amount respectively longer storms compared to nights in the “poor” condition. Graphical analysis of EDA data of participant two denoted that at least his first three nights seemed to be in accordance with the hypothesis. For participant three and four this was not the case.

Mackworth Clock Test

Regarding the EDA during the vigilance task, there have been individual differences as well. The differences in SCL during the vigilance task (indicated by a test statistics as high as .823) are shown in Figure 2.1 and 2.2. Generally speaking, only with respect to the average SCL did both participants display a higher SCL after a night of good sleep (graphical analysis), according to what has been expected. However, taking a look at each MCT apart, one can see that only during the MCT “after a good night”, both EDAs were almost the same for participant four. The average number of SCR’s and average total amplitude differed per condition for each participant. For participant three the mean after a good night was higher for all three variables, the mean after a good night for participant four was only higher in the case of SCL. (For graphical analyses respectively hit- and miss-rate see Appendix 7).

Figure 2 Example of EDA data; Night one to four of participant one

In this Figure the EDA can be seen in mSiemens per night (first blue line) as well as the first sleep storm per night is marked. In addition, it is possible to see the fluctuations in body temperature (second blue line) during the night and the acceleration (colored lines under the two blue lines).

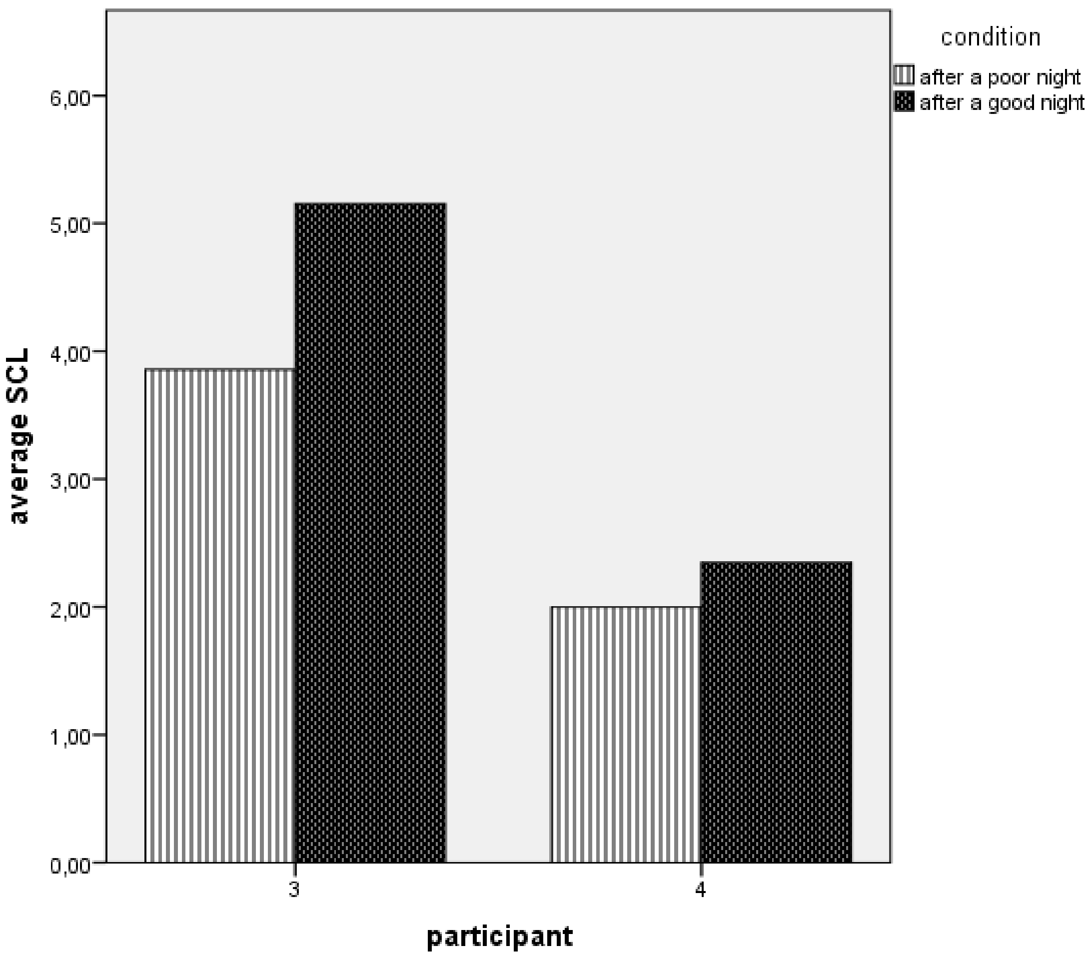

Figure 2.1 Average SCL (in mSiemens) during the Vigilance task for participant 3 and 4 per condition

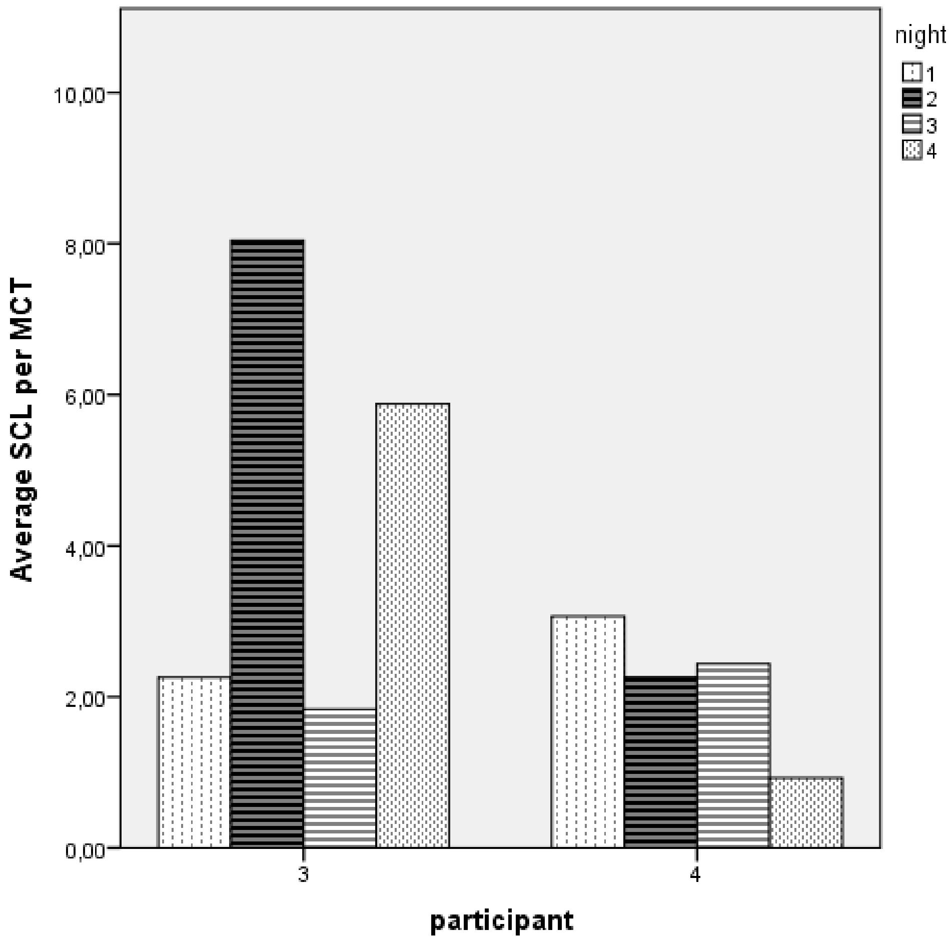

Figure 2.2 Average SCL (in m Siemens) during MCT for each participant for MCT apart (Participant 3: night 1 and 2 = good nights; participant 4: night 2 and 3 = good nights)

Discussion

Hypotheses

The current study confirms earlier findings by Roehrs et al (1996 as cited by Lund et al., 2010) that the majority of students (in this study three of four) actually sleeps less (about 7 hours per night) than what has been found to be necessary to maintain physiological and psychological well-being. That most of them also suffer from daytime sleepiness as stated by Takahashi (2003) was insinuated by means of the KSS. The majority of the rated values lay between 5 (neither sleepy, nor alert) and 8 (sleepy, having trouble staying alert) suggesting that the changing sleep patterns coming along with changes in lifestyle of a student are problematic.

Indeed, the present study aimed to achieve more information about EDA as new measurement device in sleep research. It has been found that SCL might be a promising indicator of sleep quality. The results indicated that the average SCL per hour was significantly higher after a night of good sleep, suggesting a higher amount of SWS (Mirò et al., 2002), compared to a night of poor sleep. Out of personal interest, a graphical analysis has been carried out to take a look at each individual as well. Graphics showed great individual differences making future research of this concept reasonable as well as interesting.

The results concerning number of sleep storms were not clear-cut amongst others because it was complex to isolate single sleep storms as can be seen in Figure 2. Indeed, with a stronger manipulation it is expected that in future studies the results will be (significant and) in agreement with the hypothesis. Graphical analysis displayed tendencies that were in accordance with what has been found by Sano and Picard (2011). Sleep storms in the good nights began in the first quarter of the night (for participant one) as well as good nights were characterized by a higher number of storms respectively longer storms than were nights of poor sleep. Moreover, the graphical analysis revealed that for this participant the total amplitude of SCR’s, SCL and number of SCR’s were higher during good sleep as well. Graphics of EDA of participants two and four showed conformity with what has been suggested by Sano and Picard (2011) for three of the four nights, whereas participant three did not comply with what was expected. These findings suggest that the manipulation “partying” was probably not strong enough to ensure nights of poor sleep. Moreover, it highlights the fact that people differ a lot with regard to EDA making it difficult to outline a general pattern, thereby underlining the importance of future studies.

Another reference that partying might not have been a reliable manipulation was that subjective ratings did in the majority of cases not match with the assigned conditions. Indeed, subjective ratings might not coincide with reality. KSS ratings on the contrary, had a high agreement with the assigned conditions, which could also be the cause of sleep length not necessarily, sleep quality. However, given that Kaida et al (2006) revealed that the KSS has a high correlation with EEG, these ratings seem to be more reliable than ratings in the sleep diary.

Results bearing reference to the vigilance task indicated that sleep deprivation diminishes people's attention and vigilance as stated in Oken et al (2006). This could be seen on the basis of the hit-rate during the MCT after a good night and after a poor night. Participants revealed significantly more hits after a recovering night. Reaction times, false-alarms as well as misses, however, did not increase significantly after nights of poor sleep, which might have been caused by limitations during the measurement (see section limitations). The same was found with regard to sensitivity (see Appendix 5) at which a lot of participants revealed negative values. This negativity can emerge through response confusion. This means that participants responded with "Yes, I saw a signal" while their intention was to respond with "No, there is no signal" or vice versa (Stanislaw & Todorov, 1999). After talking to the participants it was found that the latter was definitely the case; however it is not sure whether this aspect was the only cause of negative numbers.

Finally, the analysis of EDA data during the vigilance test carried out for two participants did not reveal significant results, insinuating that arousal was not significantly higher after a night of good sleep. Graphical analyses showed great differences between the two individuals. Average SCL was higher for both of them after a night of good sleep, displaying tendencies being in accordance with what was revealed by Horne et al (1978) and the formulated hypothesis. The results of the graphical analysis considering the two other variables provided contrarian values for both participants. Participant three showed a higher total amplitude as well as a higher amount of SCR's during the test after nights of good sleep thus complying with the hypothesis. Participant four, in contrast, offered a higher total amplitude after nights of good sleep but at the same time a smaller number of SCR's in that condition. These finding have no clear-cut explanation and should thus be further studied in future research including statistical analysis of the individual.

All in all it is to say that the SCL seems to be a reliable indicator of sleep quality. In addition, the number of sleep storms and their onset during the night might be a promising indicator of slow wave sleep. Indeed this explorative study suggests that EDA is a promising measurement device concerning sleep research especially with respect to the different concepts studied.

Limitations

During the present study, there were also a number of limitations. Beginning with the fact that participants were not representatives of the population as they all belonged to the experimenters' closer environment. Moreover, since time was limited, the research investigated only a very small group of people, diminishing reliability. Another aspect that surely limits the study is the fact that one of the participants was the experimenter herself. This makes the data referring to this participant (one) less reliable as the experimenter e.g. knew all about the MCT and its settings, possibly influencing her performance. She might have been occupied with respect to her sleep as well. She knew that it was important that the nights of condition one were of poor quality which may have influenced her sleep unconsciously as well as her subjective ratings.

Furthermore there were some problems concerning the EDA measurements. The last three nights of participant four had a sample size of 8Hz instead of 32Hz, which probably occurred as a result of recharging problems with the laptop. This of course brings along differences in EDA data. Moreover, arising problems with reference to the laboratory forced the experimenter to change locations for the last two test moments (of the MCT), which might have had some influence on the performance of the vigilance task on day three and four. The data of the MCT also revealed that, although settings were double checked, in more than half of the test moments the signal number did not add up to a total of 60 rather being somewhere between 48 and 60. In addition, sleep diaries revealed that participants one, two and four did not party in the first night, at least not with bodily activity (dancing), which might have been of influence on their sleep at this night.

Future Research

As an explorative study, this research tried to find out which concepts of EDA are as well interesting as promising for sleep research, so that future studies know what has to be investigated. For future research it would be of advantage to make use of more than four participants but more importantly to employ more moments of measurement. It is crucial to find a better manipulation to make participants actually experience a night of poor sleep quality when this is applicable for the design. If more can be found out respectively the concepts that have been studied in the present research, it is possible to build up projects studying sleep in a natural environment, thus receiving more realistic information about sleep. As was mentioned in the introduction, sleep has (amongst others) a crucial role for academic performance. Ahrberg et al. (2012) states in his article "The interaction between sleep quality and academic performance" that "Sleep seems to stabilize as well as enhance a wide variety of memory contents" (Diekelmann & Born, 2010 as cited in Cipolli, Mazzetti & Plazzi, 2013). This information underlines the crucial role of sleep for learning. Further studies reveal that sleep is important to be able to consolidate new information and to improve memory. This means that sleep is not only necessary to strengthen memories, but also for the successful encoding of information, which is a major aspect of learning. Therefore, it might be interesting to find out under which sleep circumstances information is best encoded so that in return, interventions can be set up to improve students sleep and thereby their performance in university (or school). This is only one amongst many topics that could be of interest for future research.

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Appendices

Appendix 1

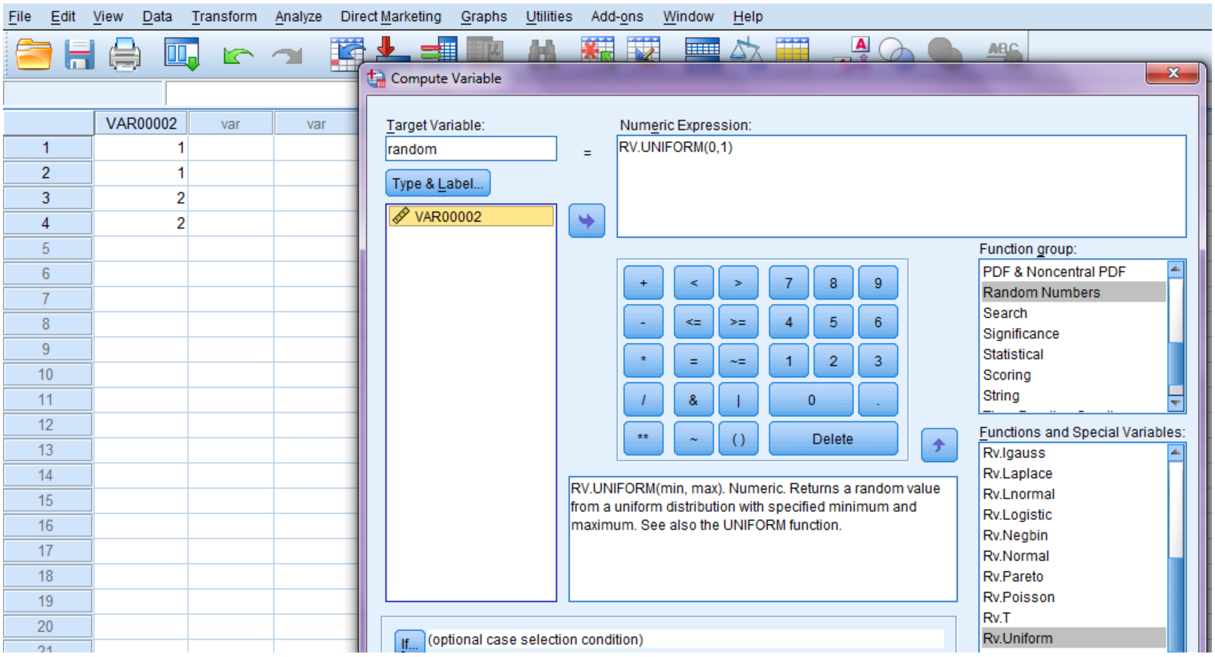
Signal Detection Theory

The signal detection theory (SDT) states that either a signal to be detected is present or that this is not the case. This brings about two possible answers. *Yes, I see a signal* or *No, there is no signal*. However, people sometimes cannot make a perfect distinction between "noise" (no real signal) and the actual signal which results in the following four possibilities: 1. Correctly detect a signal (hit) 2. Say there is no signal when this is the case (correct rejection) 3. Detect a signal although no signal is present (false alarm) 4. Fail to detect a present signal (miss). This signal detection is influenced by a bias called sensitivity, which can be thought of as a bottom-up process expressing how good a person is able to discriminate the signal from the noise (Wickens et al., 2004, p.84). Sensitivity can be influenced by the acuity of the senses as well as the signal-to-noise ratio.

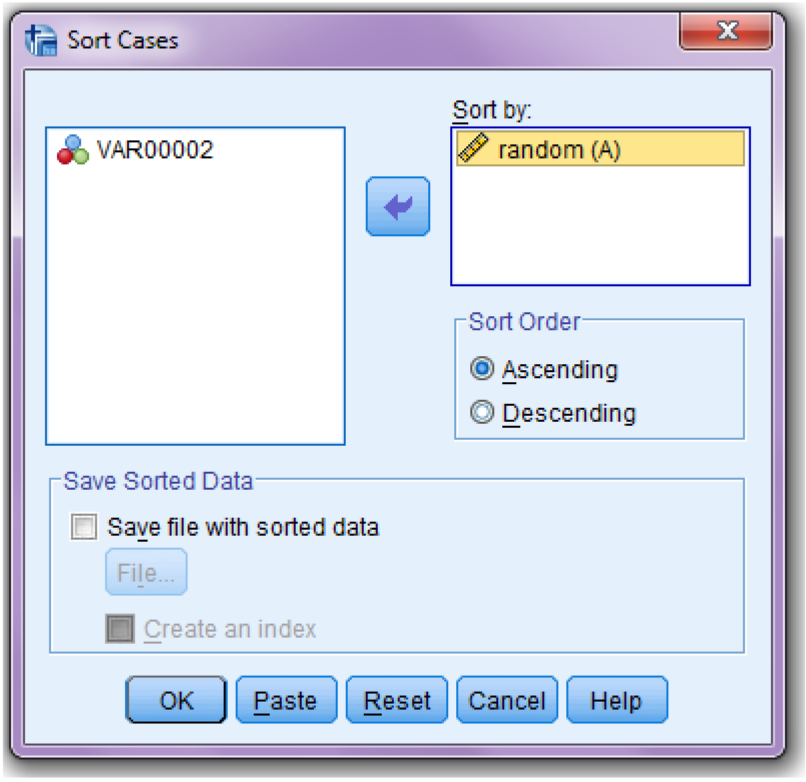
Appendix 2

Randomization by means of SPSS

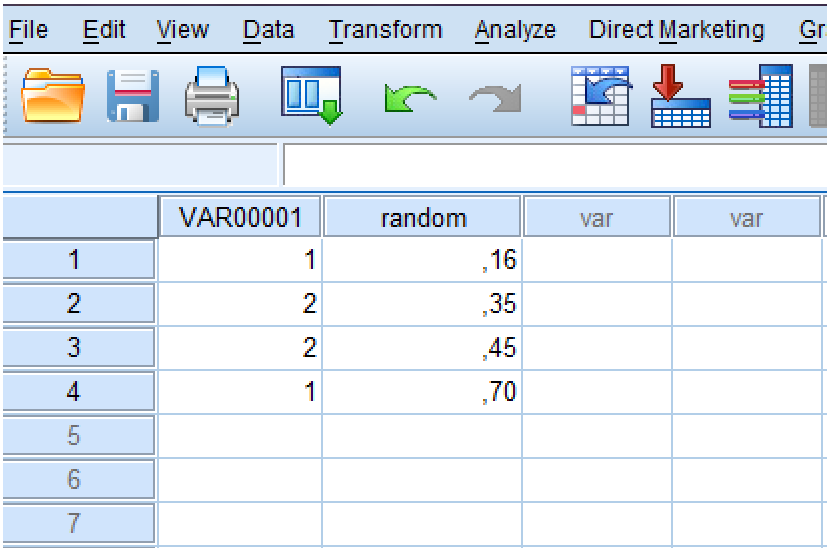
As a randomization test has been chosen to analyze the data in the present study, it is crucial to also assign conditions randomly per participant. This could be done with aid of SPSS. First of all, there were two conditions which were to be assigned to each participant twice (participant: 2x condition 1 and 2x condition 2). This could be done by inserting 1,1,2,2 into a column in SPSS and then go to the menu, choose “transform” → “compute variable”. After this, a window pops up with different sub-windows under which “numeric expression” and “function group”. In the latter window “random numbers” and in the window below (functions and special variables) “RV uniform” needs to be selected. “RV uniform” needs to be chosen and put into the first sub-window. The two question marks are then replaced by a “0” and a “1” as there are two options to choose of. At last give this variable a name e.g. „random”.



Afterwards “sort cases” has to be chosen under the menu “data”. Another window pops up and one needs to sort the cases by the new variable.



After this last step, SPSS sorts the cases, in this case conditions, in random order. This procedure has been carried out four times, for each participant once. The randomization, as in the example below, resulted for participant one, two and four. Participant three received the conditions in another order.



	VAR00001	random	var	var
1	1	,16		
2	2	,35		
3	2	,45		
4	1	,70		
5				
6				
7				

Appendix 3

Utilized macro

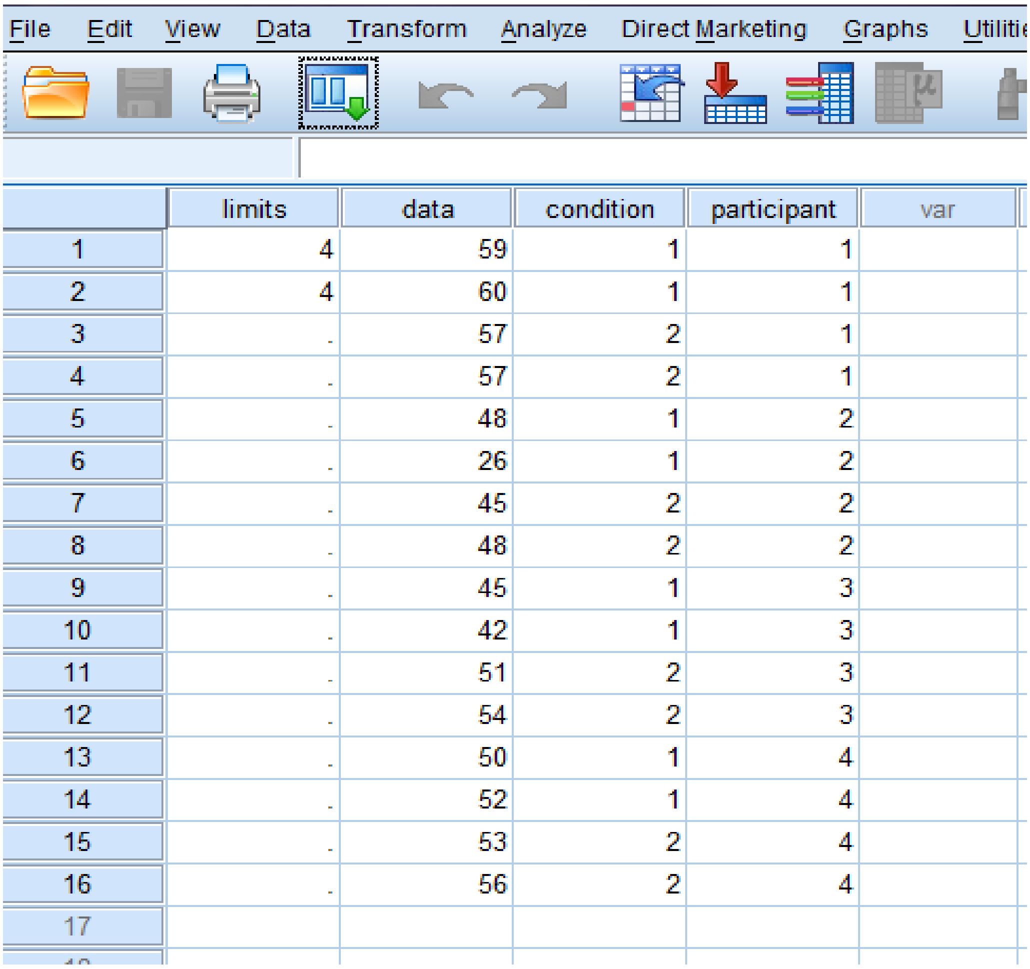
To run the macro one has to click on run → all

```
Set mxloops 5000.
matrix.
Get limits/variables=limits/missing=omit.
Get data/variables data condition participant/missing omit.
compute ncase=limits(1).
compute nswaps=limits(2).
compute nobs=ncase*nswaps.
compute total={0,0}.
Loop obs=1 To nobs.
compute total(data(obs,2))=total(data(obs,2))+data(obs,1).
End Loop.
compute test1=(total(2)-total(1))/(nobs/2).
Print test1/title="test statistic".
compute nperm=2001.
compute results=uniform(nperm,1).
compute results(1,1)=test1-test1/1000000.
Loop perm=2 To nperm.
Loop Case = 1 To ncase.
Loop n= 1 To nswaps.
compute k=trunc(uniform(1,1)*(nswaps-n+1))+n+nswaps*(Case-1).
compute obs=n+nswaps*(Case-1).
compute temp=data(obs,1).
compute data(obs,1)=data(k,1).
compute data(k,1)=temp.
End Loop.
End Loop.
compute total={0,0}.
Loop obs=1 To nobs.
compute total(data(obs,2))=total(data(obs,2))+data(obs,1).
End Loop.
```

```
compute test1=(total(2)-total(1))/(nobs/2).
compute results(perm,1)=test1.
End Loop.
compute absres=Abs(results).
compute pos1=0.
compute pos2=0.
Loop k=2 To nperm.
Do If results(k,1)>=results(1,1).
compute pos1=pos1+1.
End If.
Do If absres(k,1)>=absres(1,1).
compute pos2=pos2+1.
End If.
End Loop.
Print pos1/title="count of arrangement statistics at least as large".
compute prob1=(pos1+1)/nperm.
Print prob1/title="one tail probability".
Print pos2/title="count of arrangement statistics at least as large in abs value as abs(test)".
compute prob2=(pos2+1)/nperm.
Print prob2/title="two tail probability".
End matrix.
```

Appendix 4

Formsheet SPSS (with data from Mackworth Clock test)



	limits	data	condition	participant	var
1	4	59	1	1	
2	4	60	1	1	
3	.	57	2	1	
4	.	57	2	1	
5	.	48	1	2	
6	.	26	1	2	
7	.	45	2	2	
8	.	48	2	2	
9	.	45	1	3	
10	.	42	1	3	
11	.	51	2	3	
12	.	54	2	3	
13	.	50	1	4	
14	.	52	1	4	
15	.	53	2	4	
16	.	56	2	4	
17					

The column "limits" includes the number of participants in the first row, and the number of observation occasions for each participant in the second row.

Appendix 5

Results regarding EDA and Sensitivity of the Vigilance task (not significant)

Table 1.2

Number of observations, minimum and maximum, as well as mean and standard deviations of the average number of SCR's per hour per condition

	N	Minimum	Maximum	Mean	Standard deviation
Poor sleep	8	17.59	323.74	120.35	101.56
Good sleep	8	6 .34	477.97	152.84	171.63

Table 1.3

Number of observations, minimum and maximum, as well as mean and standard deviations of amplitude per hour per condition

	N	Minimum	Maximum	Mean	Standard deviation
Poor sleep	8	2.41	42.88	15.11	13.64
Good sleep	8	.27	60.2	19.40	20.65

Table 1.4

D'prime per participant per vigilance task. Condition 2 (after a night of good sleep) is indicated with bold numbers

Participant	MCT1	MCT2	MCT3	MCT4
1	2.45	**1.40**	**1.70**	1.94
2	.22	**-.30**	**-.51**	-1.55
3	**-1.35**	**-1.49**	-1.24	-.94
4	-1.32	**.39**	**.05**	.55

Appendix 6

Karolinska Sleepiness Scale

PPcode: P31___ ___ ___ ___ Initialen: ____ ____ ____ Proefleider:__________

Datum: ____-____-200___ Uur: ___ : ___ Avond - Ochtend

HOE SLAPERIG/ALERT VOELT U ZICH NU?

Kruis de beschrijving **aan** die het beste omschrijft **hoe u zich nu voelt**.

1	Heel erg alert/ extreem alert
2	Erg alert
3	Alert
4	Beetje alert
5	Noch alert, noch slaperig
6	Enkele tekenen van slaperigheid
7	Slaperig maar moet **geen moeite** doen om **alert** te blijven
8	Slaperig maar moet **moeite** doen om **alert** te blijven
9	Erg slaperig, moet grote moeite doen om alert te blijven, vechten tegen de slaap

Appendix 7

Graphical analyses vigilance task (hit- and miss-rate)

The graphical analysis of the hit-rate showed that the hypothesis was applicable for three of the four participants (see Figure 4), whereas participant one shows the reverse pattern. Bearing reference to the miss-rate, it can be seen, that three of the four participants displayed higher miss-rates after a night of poor sleep compared to a night of restorative sleep (see Figure 5).

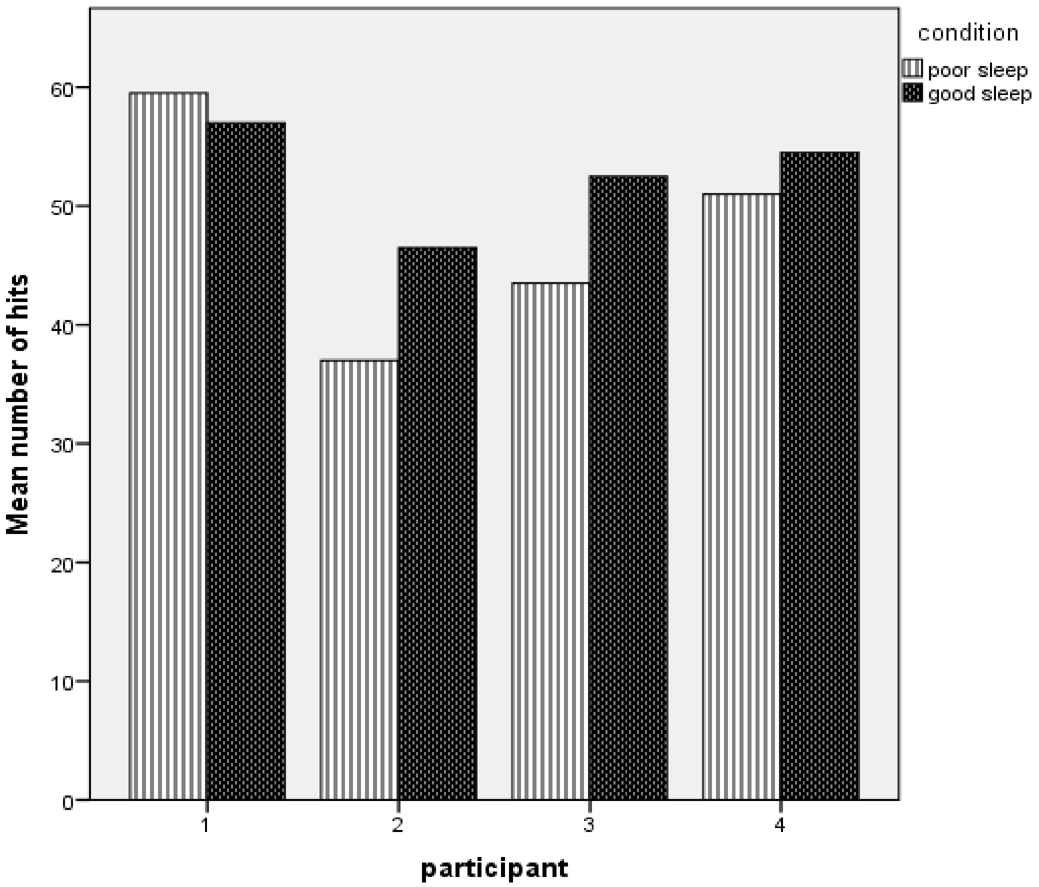


Figure 4. Average number of hits during the Vigilance task per condition for each participant

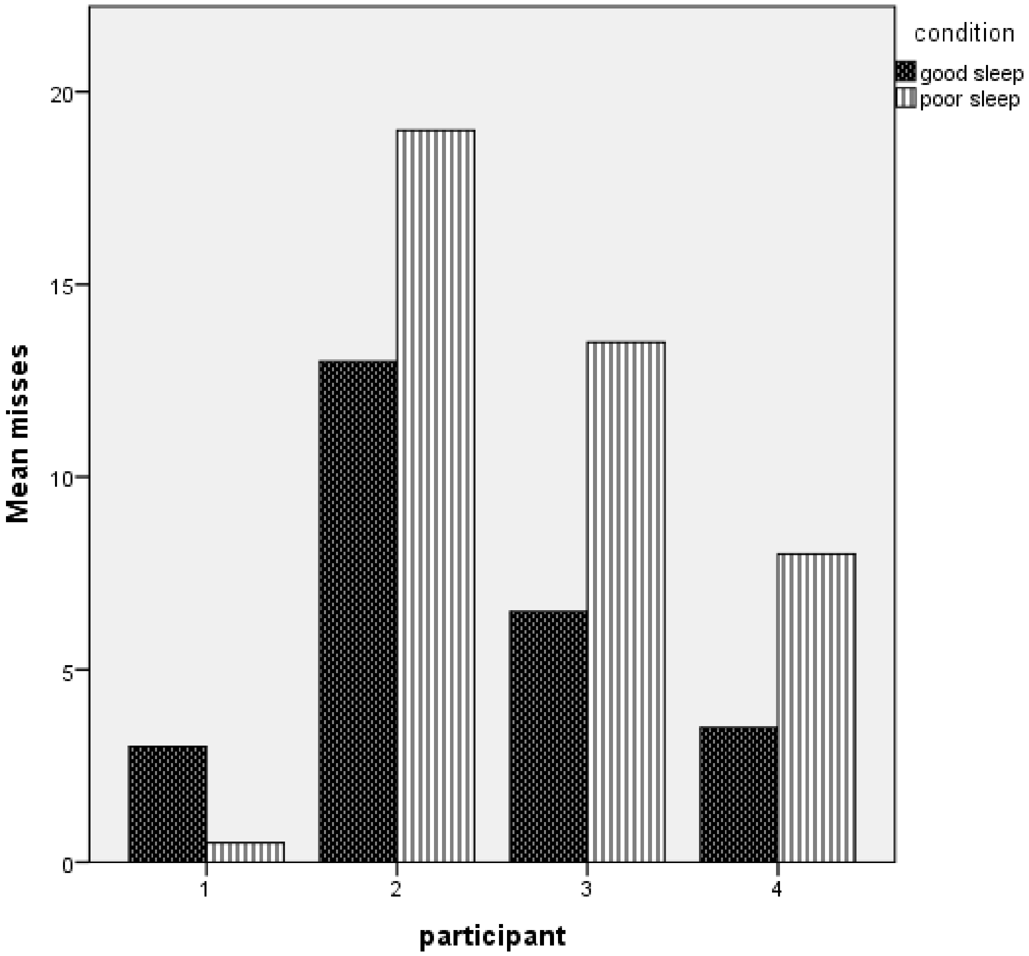


Figure 5. Average number of misses during the Vigilance task per condition for each participant